EEMS0014

U.S. DEPARTMENT OF ENERGY

SMARTMOBILITY

Systems and Modeling for Accelerated Research in Transportation

Agent-Based Transportation System Modeling with POLARIS

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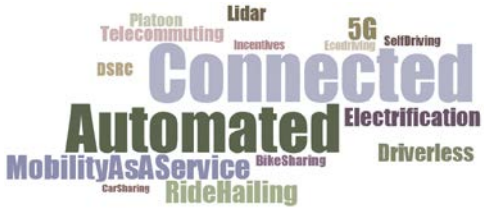
Project Overview

Timeline	Barriers
• Project start date : Oct-2016 • Project start date : Sep-2019 • Percent complete : 15%	• Very high uncertainty in estimating energy impact of new mobility solutions • Lack of common framework for proper quantitative comparisons • Available transportation modeling tools not well adapted to new mobility forms
Budget	**Partners**
• FY17 – FY19 DOE Smart Mobility Funding: $900K • FY17 Funding from multiple sources including ANL LDRD, DOE VTO, DOE FOAs, DOT/FTA: $1,200K	• Argonne National Laboratory (Lead) • George Mason University (Sub) • University of Illinois in Chicago (Sub) • Texas A&M University (Sub) • Oak Ridge National Laboratory • Lawrence Berkeley Lab

Project Relevance

Emerging mobility and transportation solutions



→ **Different traveler behavior**

→ **Different vehicle operations**

→ **Energy impact uncertain**

-90% +200%

ΔEnergy

POLARIS is a transportation modeling tool designed to provide quantitative answers

- ⇒ ***What will be the energy impact of future mobility trends?***
- ⇒ ***What technologies and policies can be leveraged for a more energy-efficient transportation system?***

Models entire metropolitan areas	Will include all modes of transportation	Highly Computationally Efficient

APPROACH

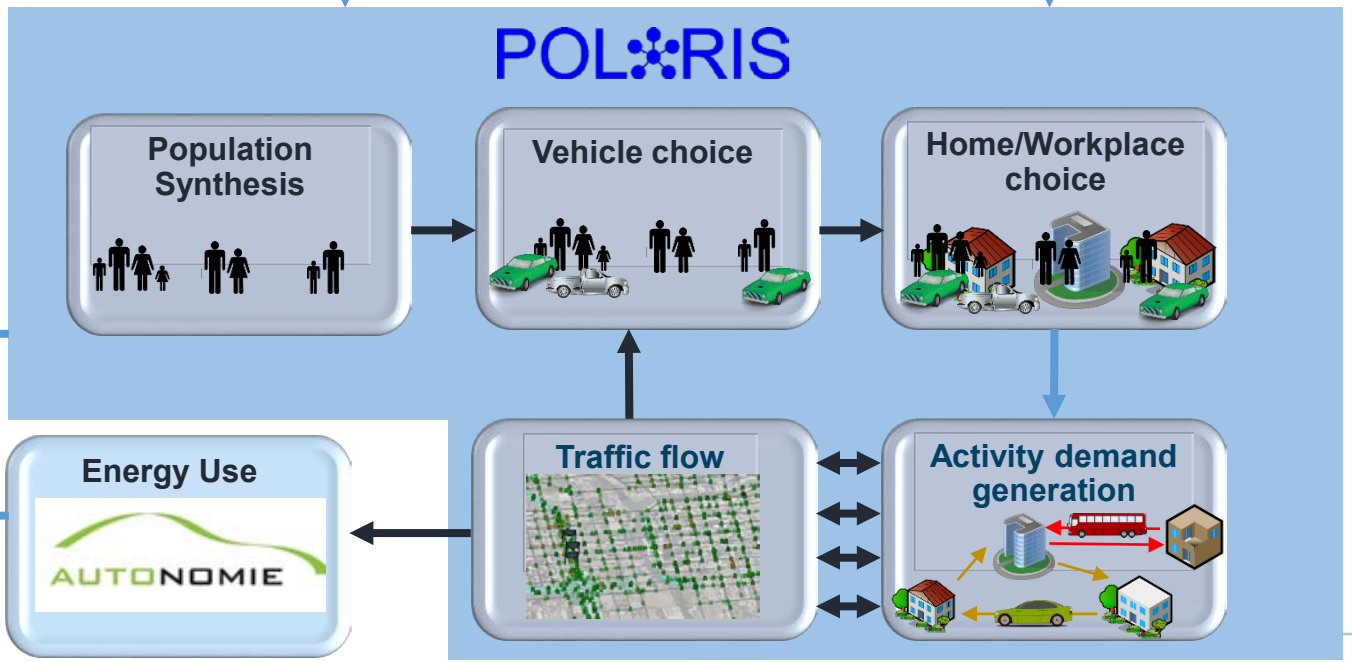
POLARIS Models the Transportation System of an Entire Metro Area

Input Data

Travel surveys
Employment data
Transp. network
Vehicle registrations
Land use, …

Forecast Scenarios

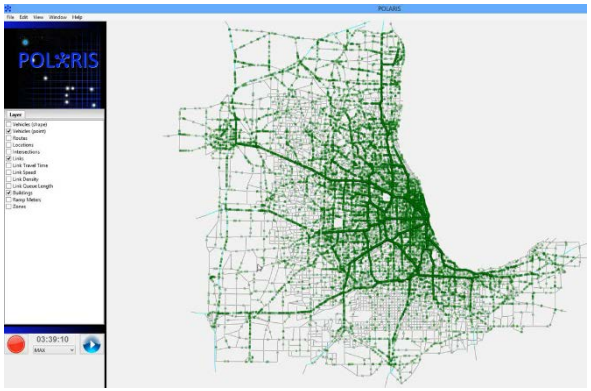
Infrastructure improvements
Population growth
Demographic shifts
New technologies
Policy environment



Results

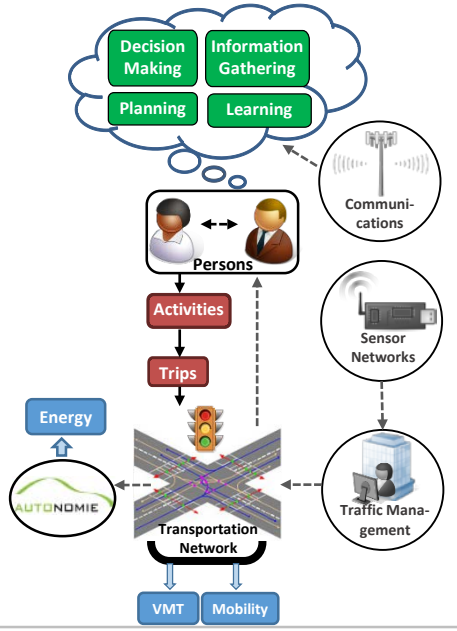
Energy consumption
VMTs
Travel times, …

POLARIS Is Uniquely Designed to Study Energy-Efficient Mobility Systems (EEMS)



- POLARIS is designed for **large-scale studies**:
  - Written in C++, multi-threading, designed for **HPC**
  - Chicago model ≈ 10M travelers ≈ 30M trips (per day) ≈ 3h simulation time (vs. several days for other tools)
- POLARIS is **open-source**, with a dedicated team of developers and transportation experts at Argonne

- POLARIS is designed from the ground-up to accommodate emerging modes and transportation technologies and evaluate their energy-impact:
  - ***Agent-based**: each traveler is modeled individually, has specific behavior and adjust behavior to transportation supply*
  - ***Activity-based**: travel demand is derived from modeled activities (work, school, leisure, etc.)*
  - ***Integrated**: **demand** (e.g. origin/destination) and **supply** (routing, traffic flow) are **integrated** in the same platform, allowing direct interactions (e.g. replanning/rerouting in case of unusual travel time)*
  - ***Energy**: POLARIS + Autonomie outputs energy consumption in the context of evolving vehicle powertrain technologies*



Approach Summary & Milestones

- POLARIS supports research across DOE's SMART Pillars:
  - CAV: how CAVs will change demand and improve operations (EEMS002, EEMS017)
  - MDS: modeling how people will travel in the context of new mobility solutions (EEMS005)
  - MM: how public transit will interact with other modes (EEMS004)
  - Urban => Development of fast calibration to be able to create POLARIS models for other cities more easily (EEMS006, EEMS15)
- POLARIS development is a multidisciplinary effort, combining behavior science, operations research, energy modeling, computer science and software engineering

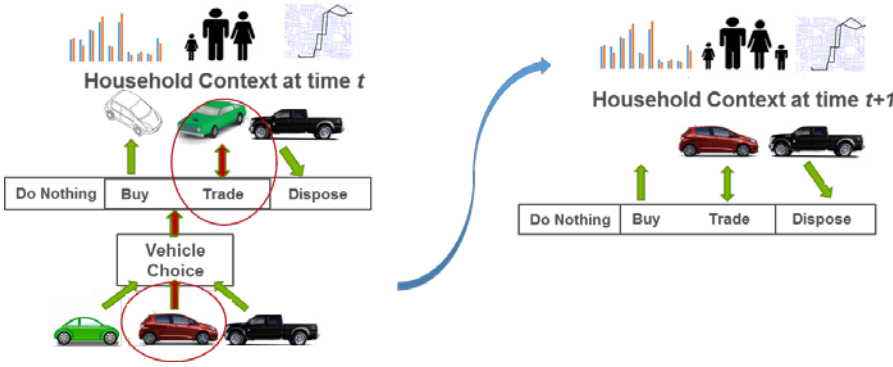
TECHNICAL ACCOMPLISHMENTS

Vehicle Assignment Models for Accurate Energy Use Forecasting

- Vehicles of different **age/class/powertrain** have different **energy** impact
- **Fleet composition** AND **vehicle assignment**, (which vehicle is used for which trip) is needed for accurate energy forecasting
  - Common approach ⇒ **registration data**
    - current depiction of ownership, not useful for forecasting
    - Random assignment within zip code ignores other important demographic aspects
  - New approach:
    - **Dynamic vehicle transaction model** (implemented framework)
    - Use input from market penetration model (ORNL's MA3T) to predict future market distribution

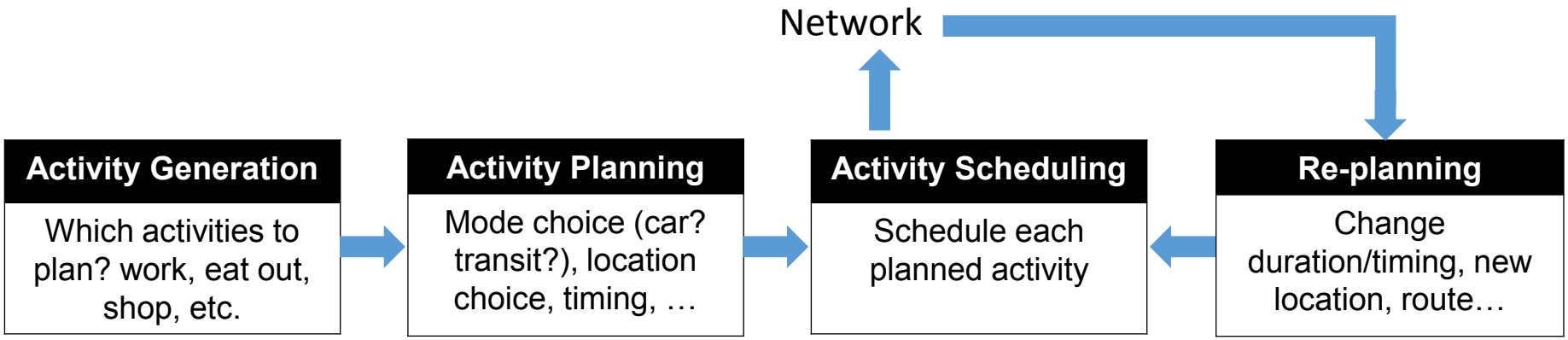
POLK / MA3T
(Regional Market Penetration)

Dynamic vehicle transaction model



- Developed **vehicle selection framework**:
  - Vehicles modeled as agents to be shared; mode selection accounts for vehicle availability at trip start

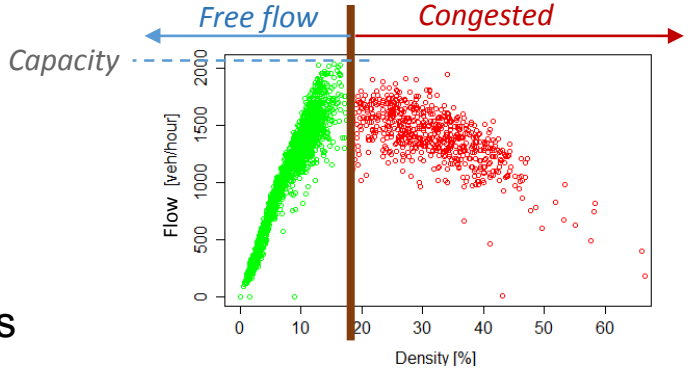
Modeling Travel Activities and Choices to Capture how Travelers Use Mobility Solutions



- In POLARIS, trips are generated by the need for a traveler to carry out an **activity**
- With emerging mobility solutions and lifestyles, it is critical to properly capture the complexity of decision making, as travelers will have more decisions to make:
  - **to travel or not**: telecommuting, online shopping, etc.
  - **pick transportation modes**: car, TNC, bike share, transit, etc.
  - adjust to **policy/incentives** (e.g. congestion pricing), **travel times** and **comfort** (e.g. can watch a movie in a self driving car)
- Improving existing models:
  - Nested choice models framework
  - Hazard-based activity generation: to account for opportunistic activities
  - Optimization-based scheduling and conflict resolution
  - Dynamic time of day choice model

Enhanced Traffic Flow Module to Model Changes in Travel Times and Vehicle Speeds Due to CAVs

- POLARIS traffic flow module uses Newell's model, and relies on **fundamental diagram,** which describes how **density** (% of space occupied by vehicles) and **flow** (veh/hour) of vehicles are related
- New model under development will use fundamental diagrams that depend on road features, traffic conditions and number of CAVs on the link
- Diagrams will be generated from large-scale parametric studies using a traffic flow micro-simulator developed by Texas A&M



Inputs

Road Features
Type, number of lanes, speed limit, etc.

Volume
Low/medium/high

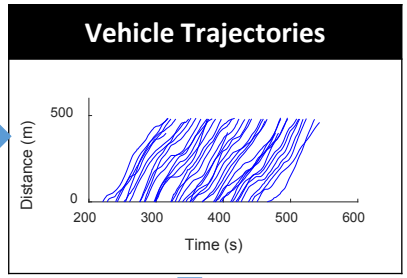
Technology Distribution
%Baseline vs. %AV vs. %CV

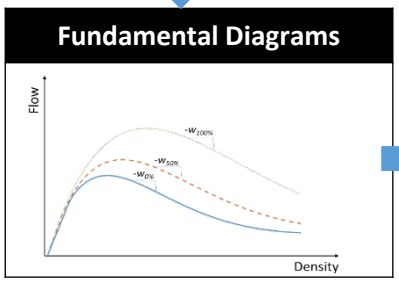
Parametric studies using Traffic flow Simulation

Human driving
Mixed heuristic/probabilistic model (prospect theory)

Connected Vehicle
Intelligent-Driver Model

Automated Vehicle
Based on deep-learning used for automated driving

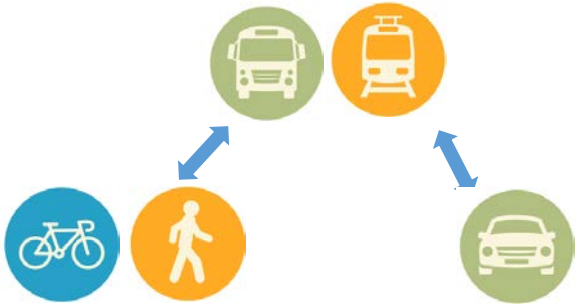




POLARIS

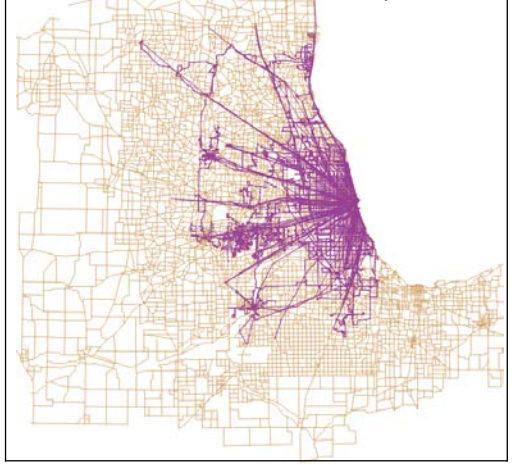
Multimodal Travel with Public Transit under Development*

- **Objectives**: model travel using multiple modes, e.g.:
  - *Walk/bike and transit*
  - *Park-and-ride (drive and transit)*
  - *Drive the entire route*
- In POLARIS, this involves many **new developments**:
  - 3 three layers of **networks**: roads, transit, and walk/bike
  - **Fast multimodal router**, using A* algorithm
  - Individual **movement** of transit vehicles
  - Model of the **transit traveler experience** (waiting, connections, inability to board) and each traveler **behavior** towards it
  - Vehicle/transit vehicle **interaction on road network**
- **Progress**:
  - Fast router designed and tested (3ms/traveler)
  - Prototype developed for entire Chicago metro area
  - Integration to POLARIS in progress
  - In FY18, addition of **energy** models for transit vehicles (support for EEMS004)



Chicago Network

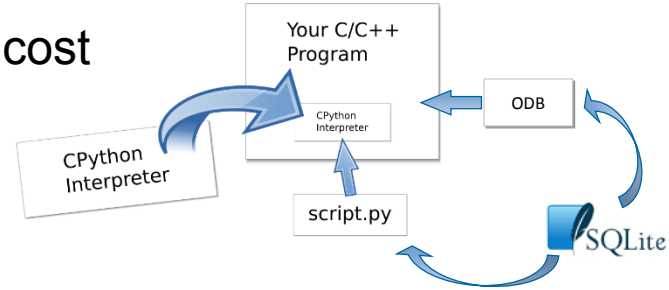
>2,000 routes
>35,000 transit nodes
>120,000 walking links
>28,000 transit vehicle trips/day
2.8M transit traveler trips



** In FY17, transit/multimodal development is funded by US DOT - FTA*

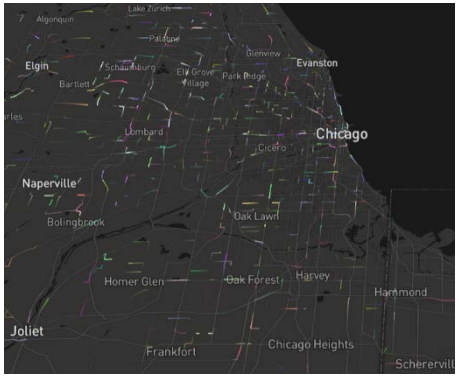
Core POLARIS Development* to Support Large-scale EEMS Studies

- **Model externalization**:
  - Allows all parameters (e.g. coefficients behavioral cost functions) to be modified without recompilation
  - Necessary for large parametric studies
  - Required for **calibration work** (EEMS0015)



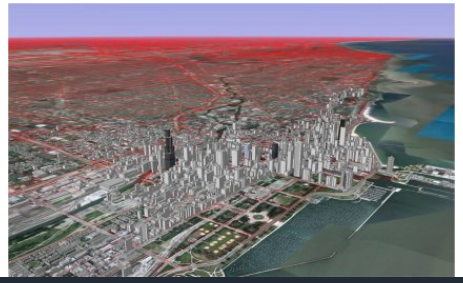
- **High-Performance Computing**:
  - Established an environment for development and testing of POLARIS on many core processors (Intel Xeon Phi), which will equip Argonne's next supercomputer, Aurora
  - Adapting code to Linux solvers, code optimization

- **Deployment** to facilitate POLARIS adoption
  - Initiated development of interface to parametrize runs
  - Developing visualization tools
  - Software lifecycle: implemented automated build and testing



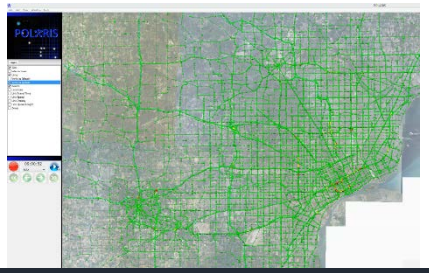
** POLARIS Core development is supported by Argonne Laboratory Directed R&D (LDRD)*

POLARIS Use Case Examples

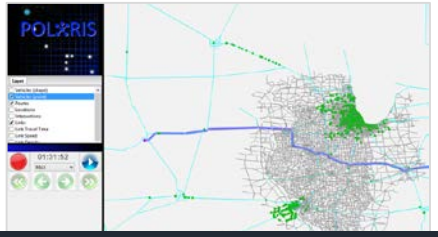


Mitigating impacts of emergency events for transit operations in **Chicago** metro area (funded by FTA)

Regional impacts of CAV (DOE SMART, EEMS017) **Chicago**

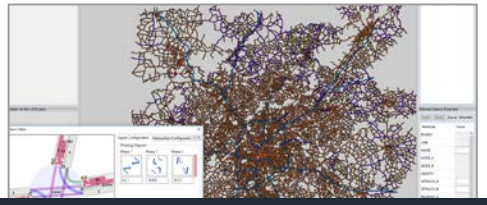


Mobility/Energy impact of future land use/population scenarios (DOE, EEMS008) **Detroit**

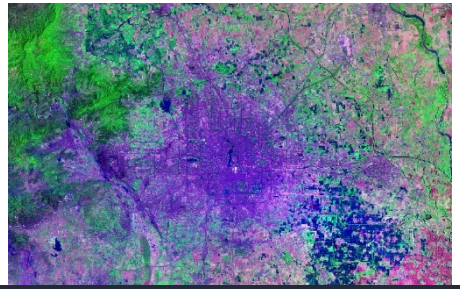


Polaris simulator used in **Illinois** long-distance travel model for IDOT

Energy impact of connectivity (DOE FOA with Univ. of Michigan, EEMS001) **Ann Arbor**, MI



Atlanta model in development for CAV studies by Georgia Tech Research Institute



Beijing model development in POLARIS (work by Beijing Institute of Technology)

Response to Previous Year Reviewers' Comments

Project was not reviewed in the past

Partnerships and Collaborations

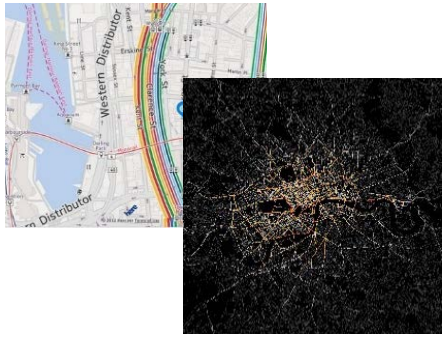
George Mason University	Development of automated POLARIS calibration framework Support on CORE developments
The University of Illinois at Chicago (UIC)	Development of behavior models
Texas A&M University	Generation of CAV fundamental diagrams for traffic flow model
University of Michigan	Collaboration on eco-routing, routing algorithms for taxis and TNCs
Oak Ridge National Laboratory	Integration with MA3T market penetration model
Berkeley Lab	Regular exchanges on activity-based modeling

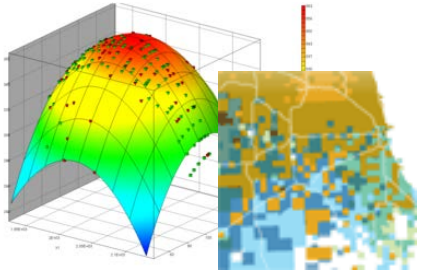
Remaining Challenges and Barriers

- Travel behavior modeling of current and future modes is highly uncertain
- Need multiple **data sets** to develop better models, especially behavior models, but travel surveys are **expensive**
- Energy benefits are highly dependent on **scenarios**. Defining and selecting appropriate scenarios while maintaining acceptable computational time is challenging
- Developing processes leveraging **HPC** is a requirement: even if POLARIS runs the entire Chicago population in 2-3h vs 2-3 days for other models, running hundreds of simulations to quantify the uncertainty is challenging
- **Transferability** needs to be improved as developing POLARIS models of new cities is expensive, both for data gathering, processing and calibration

Proposed Future Research

- Leverage **new data sources** to improve the forecast quality:
  - WholeTraveler study
  - Explore connection to big-data sources, commercial (e.g. HERE maps, StreetLight Data), public or from MPOs* (e.g. taxi, parking data)





- Develop an **automated process for calibration** of POLARIS, that will make it easier to use big data to build new cities in POLARIS

- Continue improvements in **behavioral and traffic flow models**
- Subject to future funding:

New modes (e.g. TNC)

Linkage to **land use models**

Charging & Refueling

Linkage to building energy models and **grid** models

Summary

- POLARIS is ideally suited for research on energy-efficient mobility systems, as it captures changes due to **how people travel**, but also **how vehicles move**
- POLARIS is a city-scale transportation system simulation tool:
  - **Integrated** models: **behavior** (travel demand), **operations** (traffic flow) and link to **energy** (Autonomie)
  - **Agent-based,** designed for **HPC**, models **entire metro** areas
- Further developments will improve POLARIS models and add new features to specifically address SMART Mobility needs:
  - Improved **traffic flow** models for CAVs
  - Improved **behavior** models to support decision science
  - New transport **modes**
  - Improved **usability** for increased deployment

TECHNICAL BACKUP SLIDES

Planned Development of Behavior Models for POLARIS (part of MDS Pillar)

- Activity generation model (*impact of smart mobility on activity patterns*)
  - Implement hazard-based activity generation equations in Polaris
  - Update with results of time-use analysis to shift generation curves
  - Enhance sensitivity to policy variables
  - Calibrate for Chicago and Detroit models
- Advanced scheduling and conflict resolution model (*ridesharing, shared fleet*)
  - Replace current scheduling heuristics in Polaris with optimization model (UIC)
  - Enhance resolution choice model for policy sensitivity
  - Development of vehicle scheduling (necessary for ZOV, shared fleets, etc)
- Dynamic time-of-day choice model (*incentive & pricing / transnet-type applications*)
  - Replace distribution draws with dynamic planning-constrained time choice model
  - Ensure sensitivity to transportation level-of-service, modal characteristics, etc.
  - Estimate and calibrate for Chicago and Detroit
- Household location choice and vehicle transactions (*long term impacts of smart mobility*)
  - Start developing framework for implementing long-term choices
  - Integration point with land-use (UrbanSim) and vehicle choice (MA3T, household transaction model)